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**Ishii**

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(54) **MAGNETIC DISK DEVICE, HEAD AMPLIFIER, AND CONTROLLING METHOD OF MAGNETIC DISK DEVICE**

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(22) Filed: **May 28, 2014**

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(51) **Int. Cl.**  
**G11B 21/02** (2006.01)  
**G11B 5/596** (2006.01)  
**G11B 5/012** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **G11B 5/59633** (2013.01); **G11B 5/012** (2013.01)

(58) **Field of Classification Search**

None

See application file for complete search history.

(57) **ABSTRACT**

According to one embodiment, there is provided a magnetic disk device including a magnetic disk, a magnetic head, a heater, and a control unit. The magnetic head reads out information recorded on the magnetic disk. The heater is configured to adjust a magnetic spacing of the magnetic head from the magnetic disk. The control unit is configured to change a bias amount of the magnetic head according to setting of current flow through the heater.

**13 Claims, 13 Drawing Sheets**

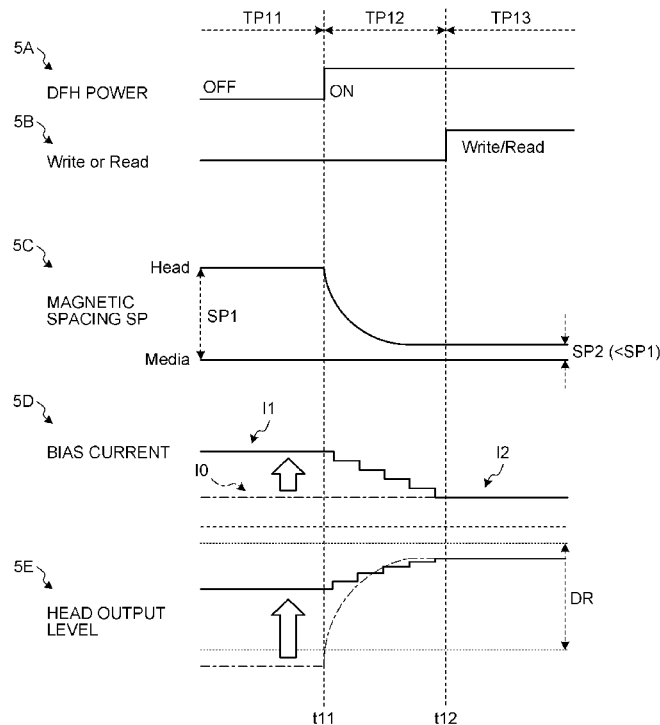


FIG. 1

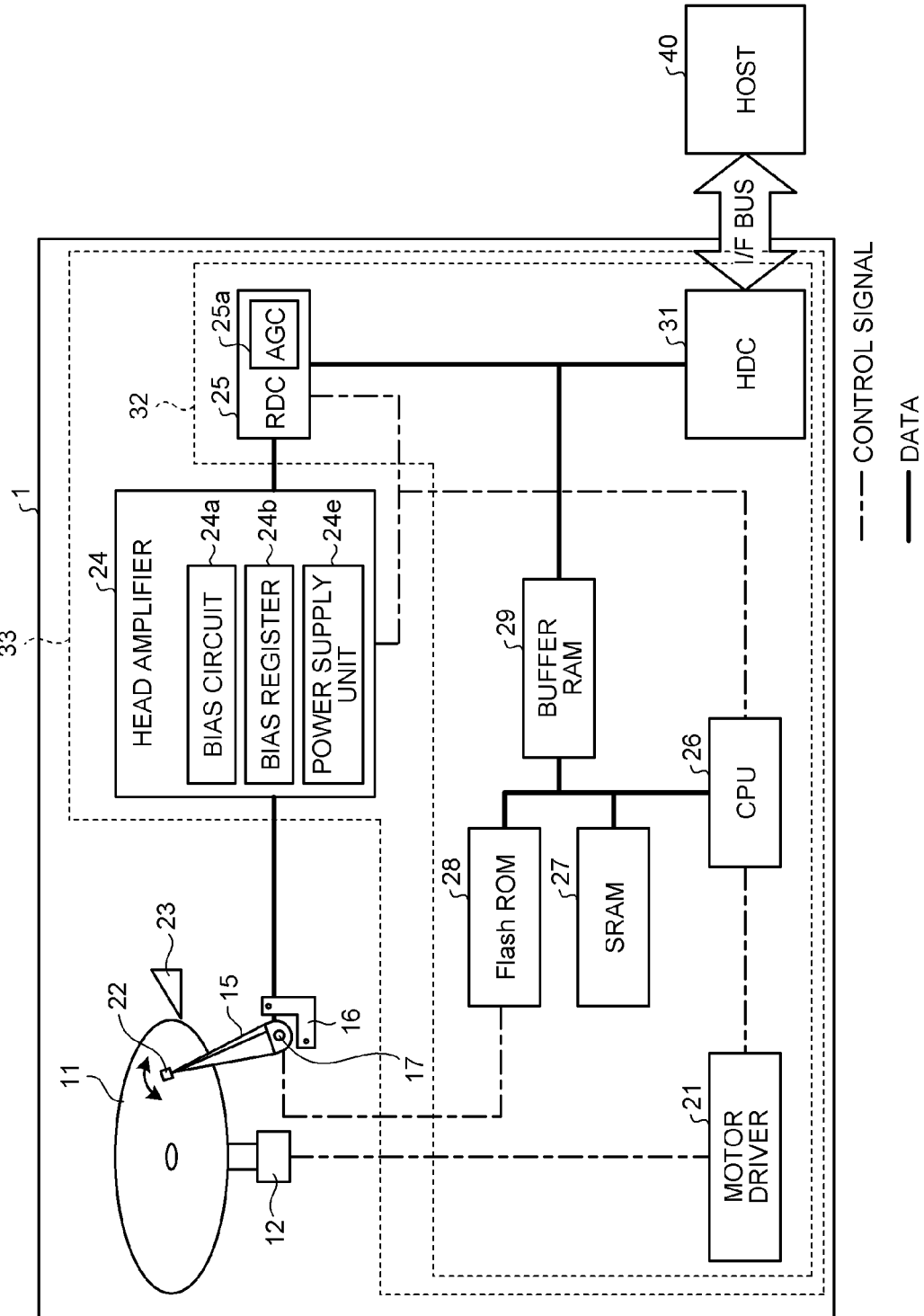


FIG.2

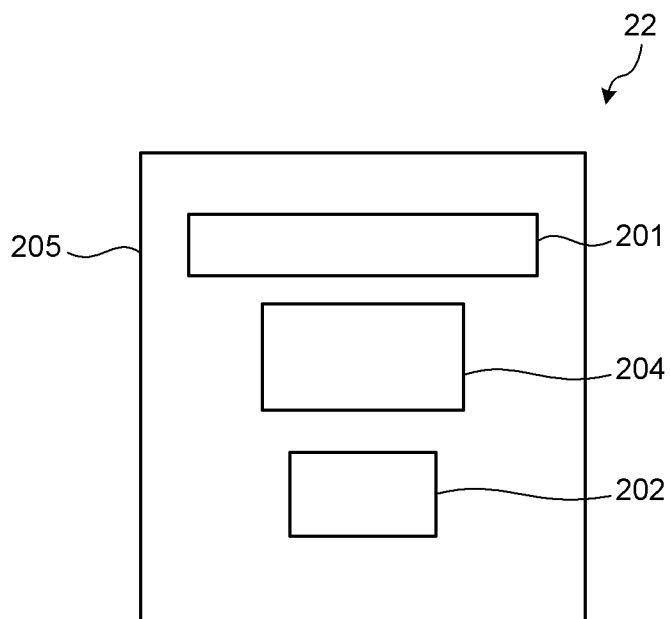


FIG.3

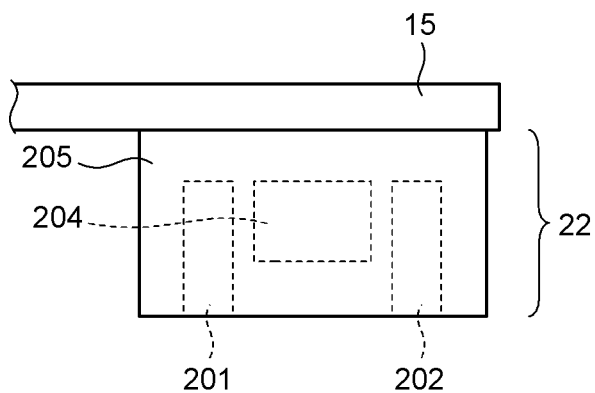


FIG.4

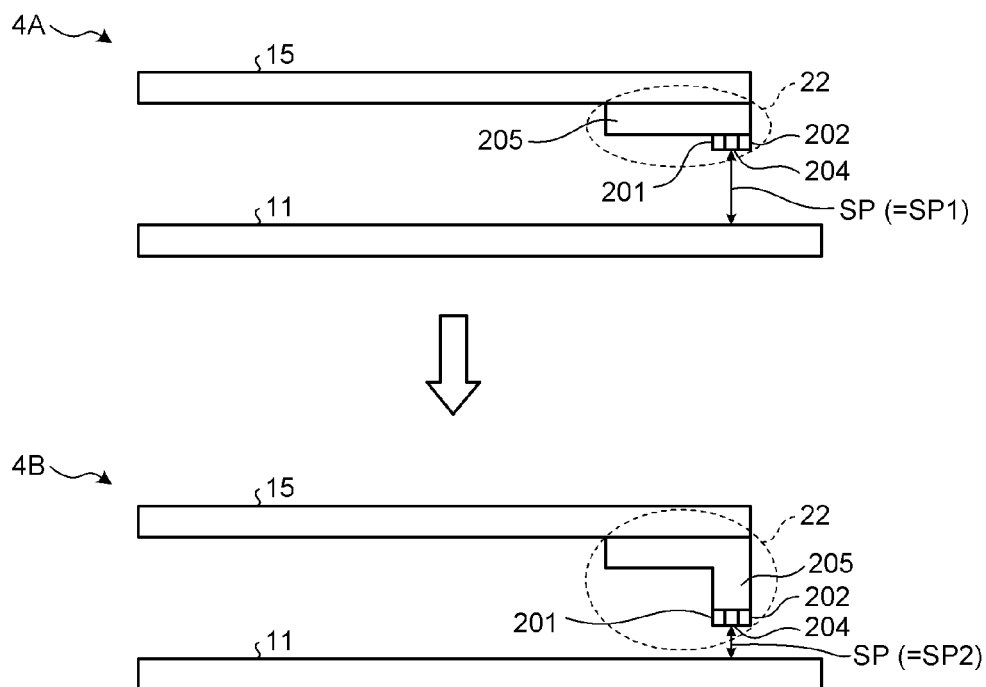


FIG. 5

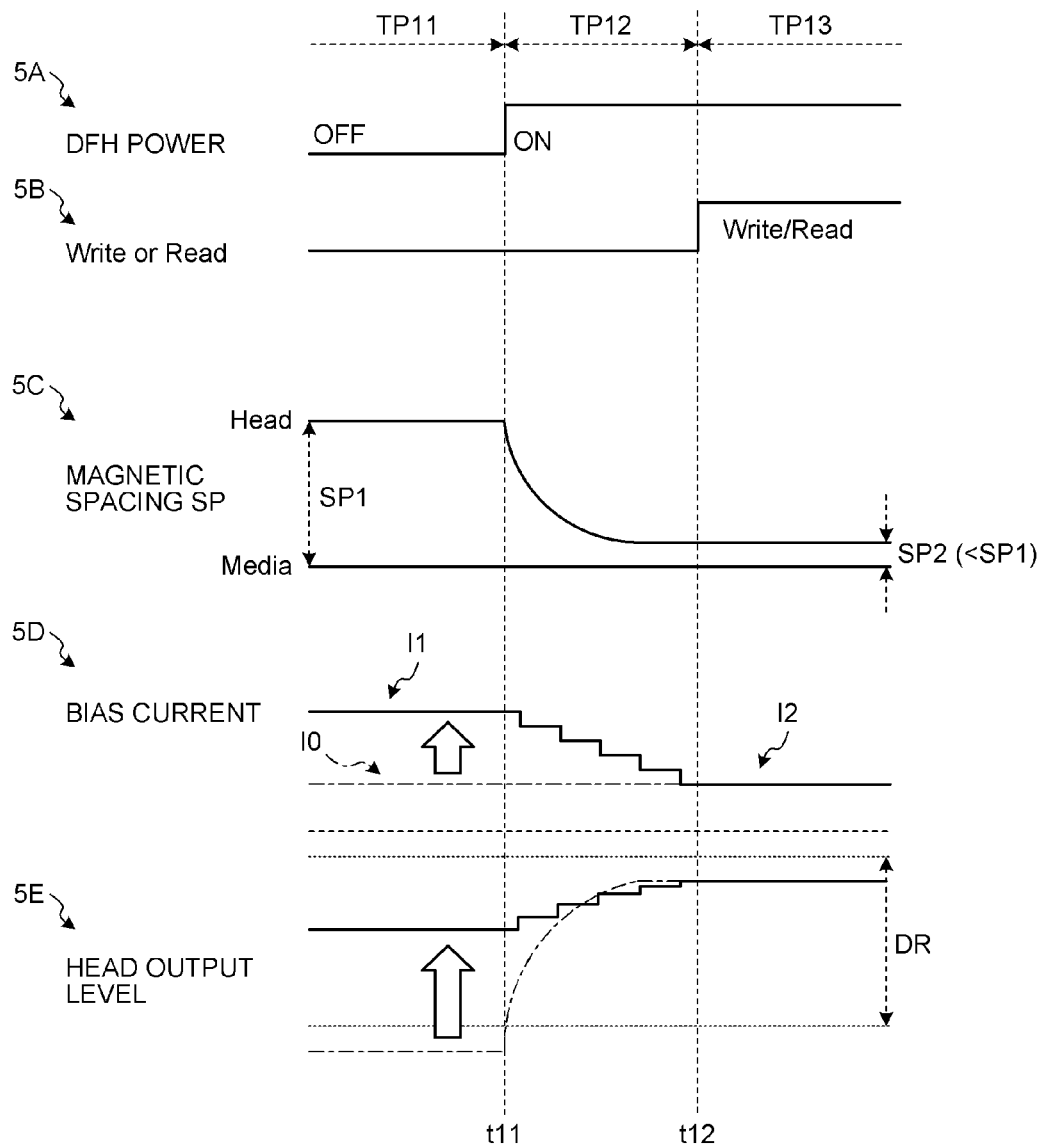


FIG. 6

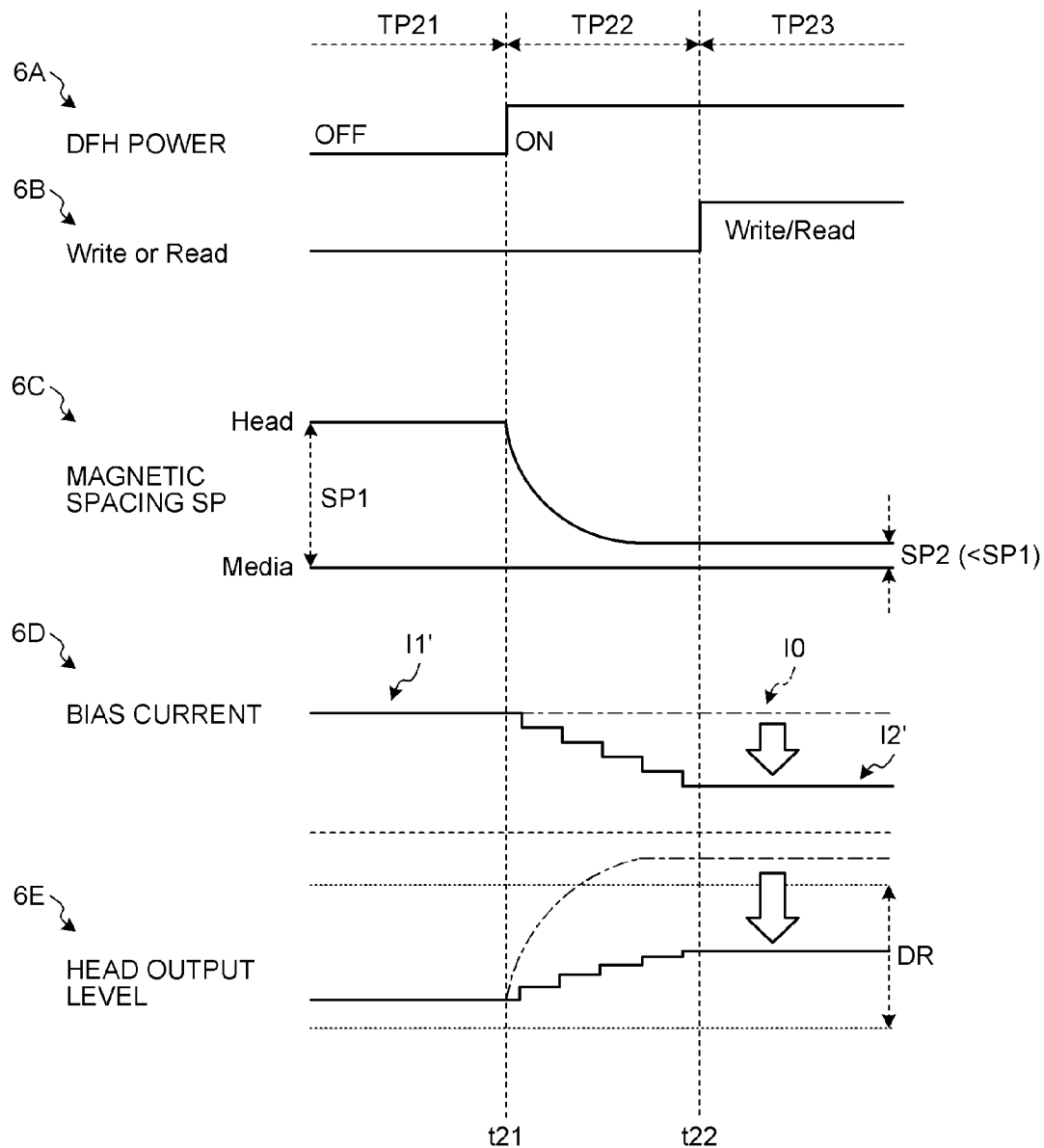


FIG. 7

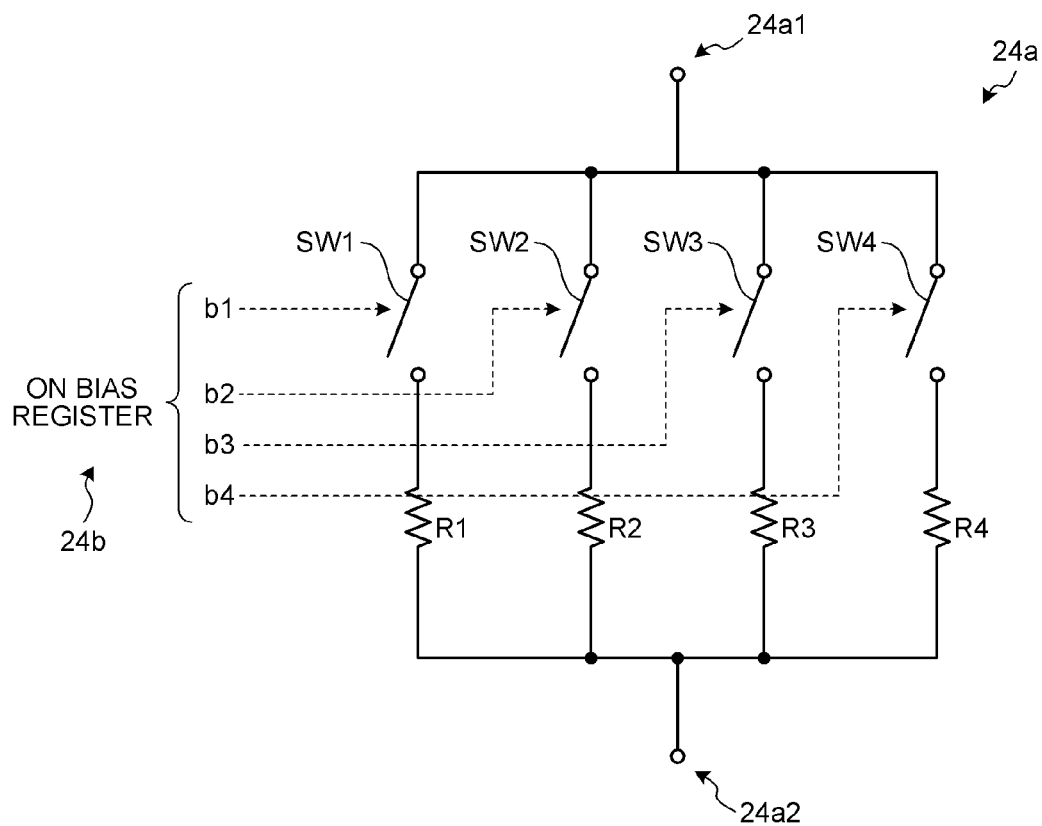


FIG.8

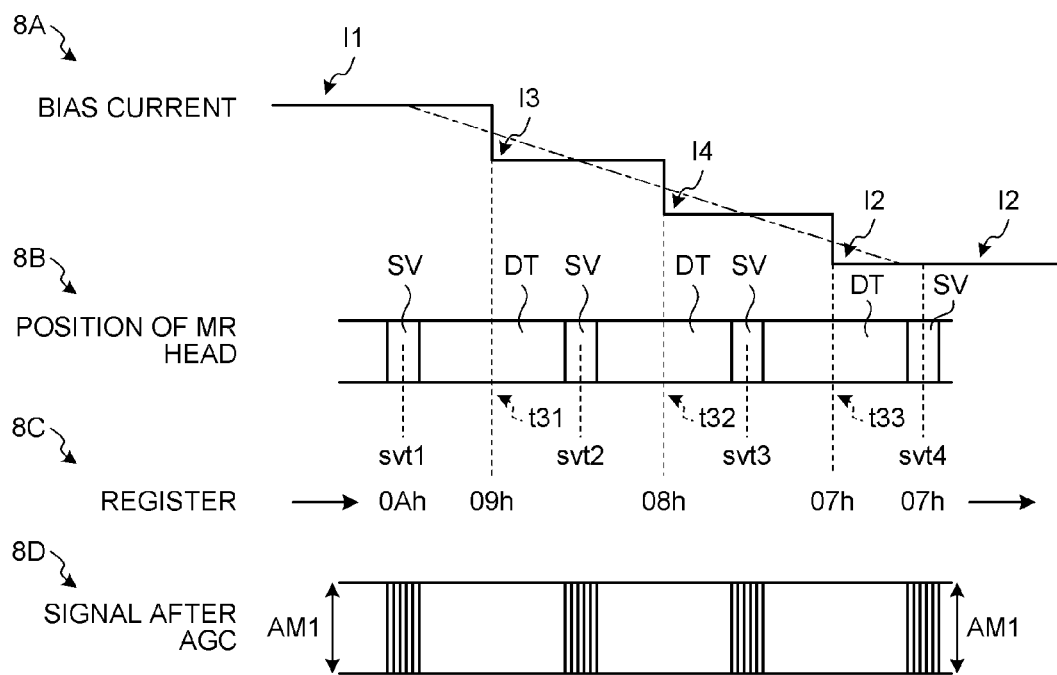




FIG. 9

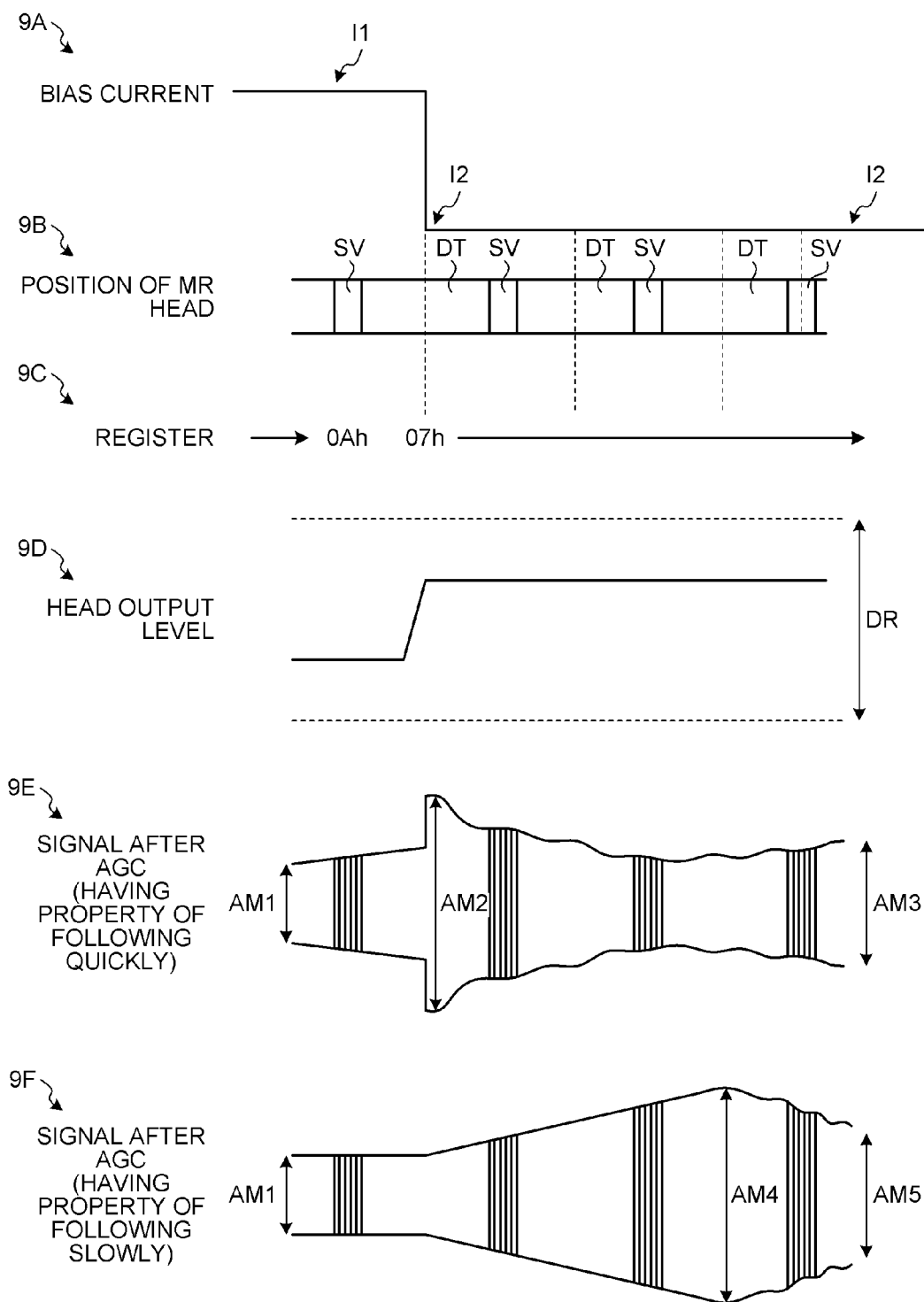


FIG. 10

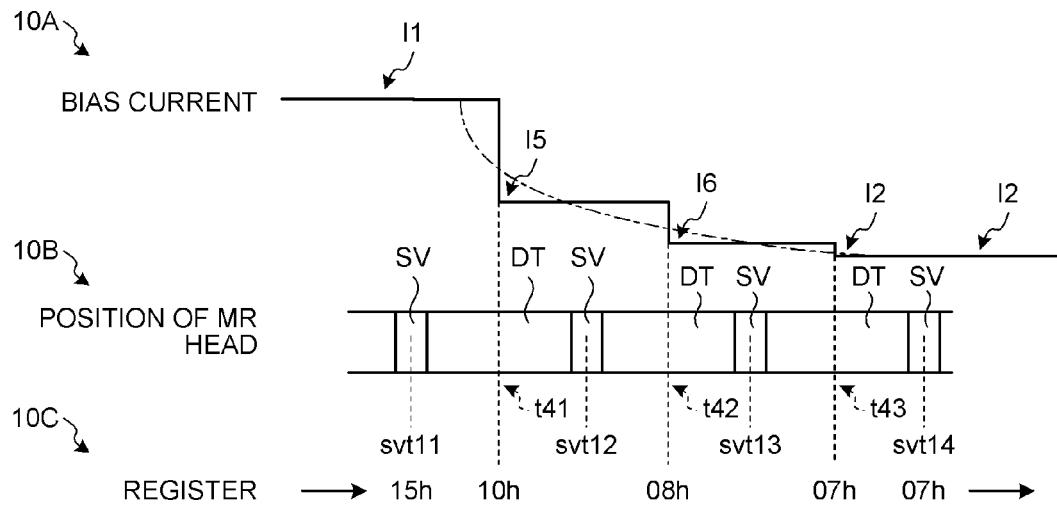


FIG. 11

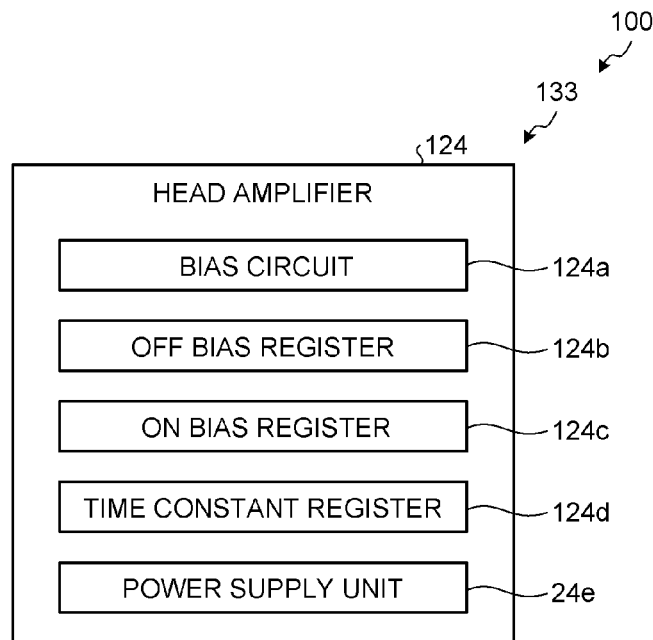


FIG. 12

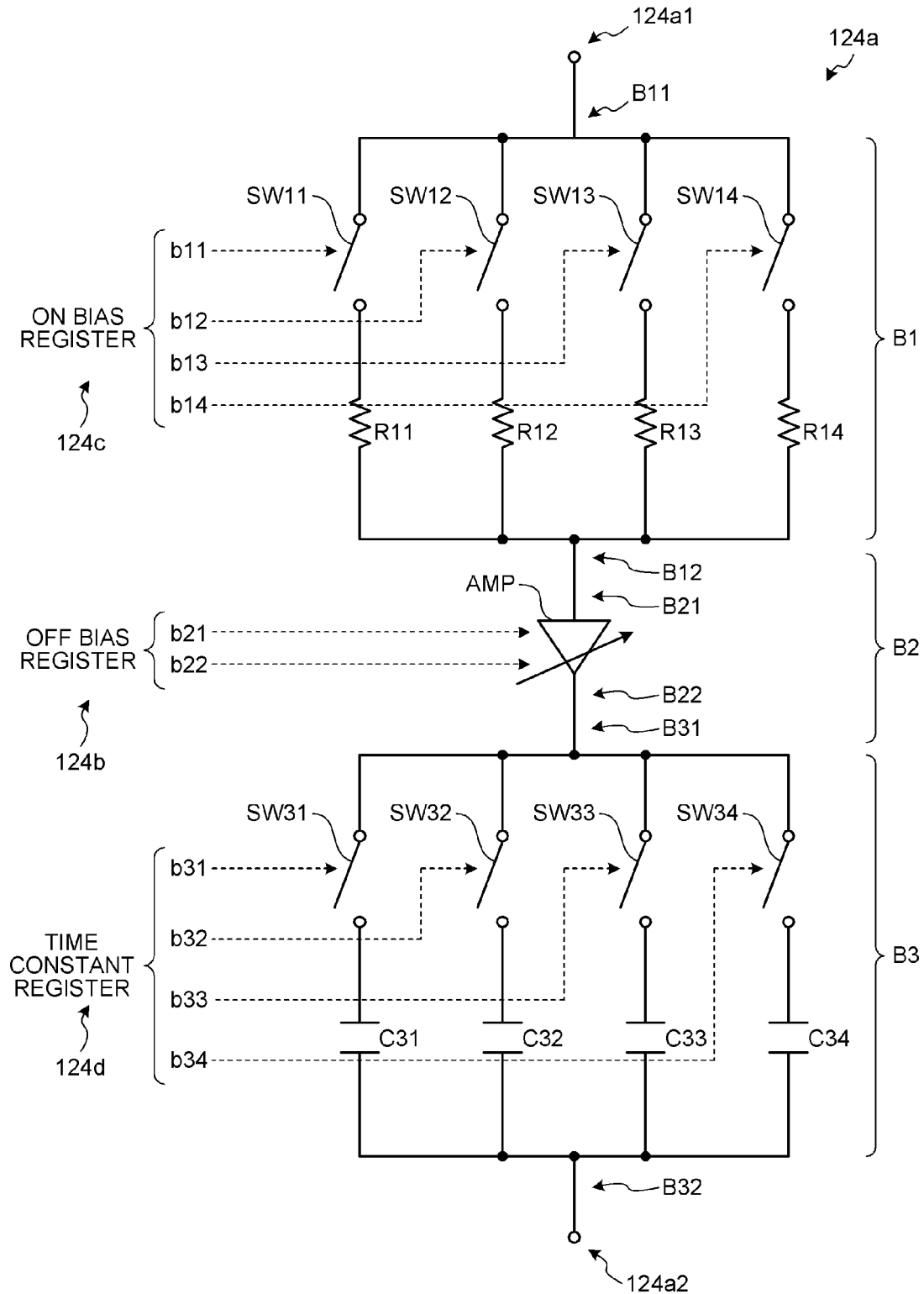


FIG.13

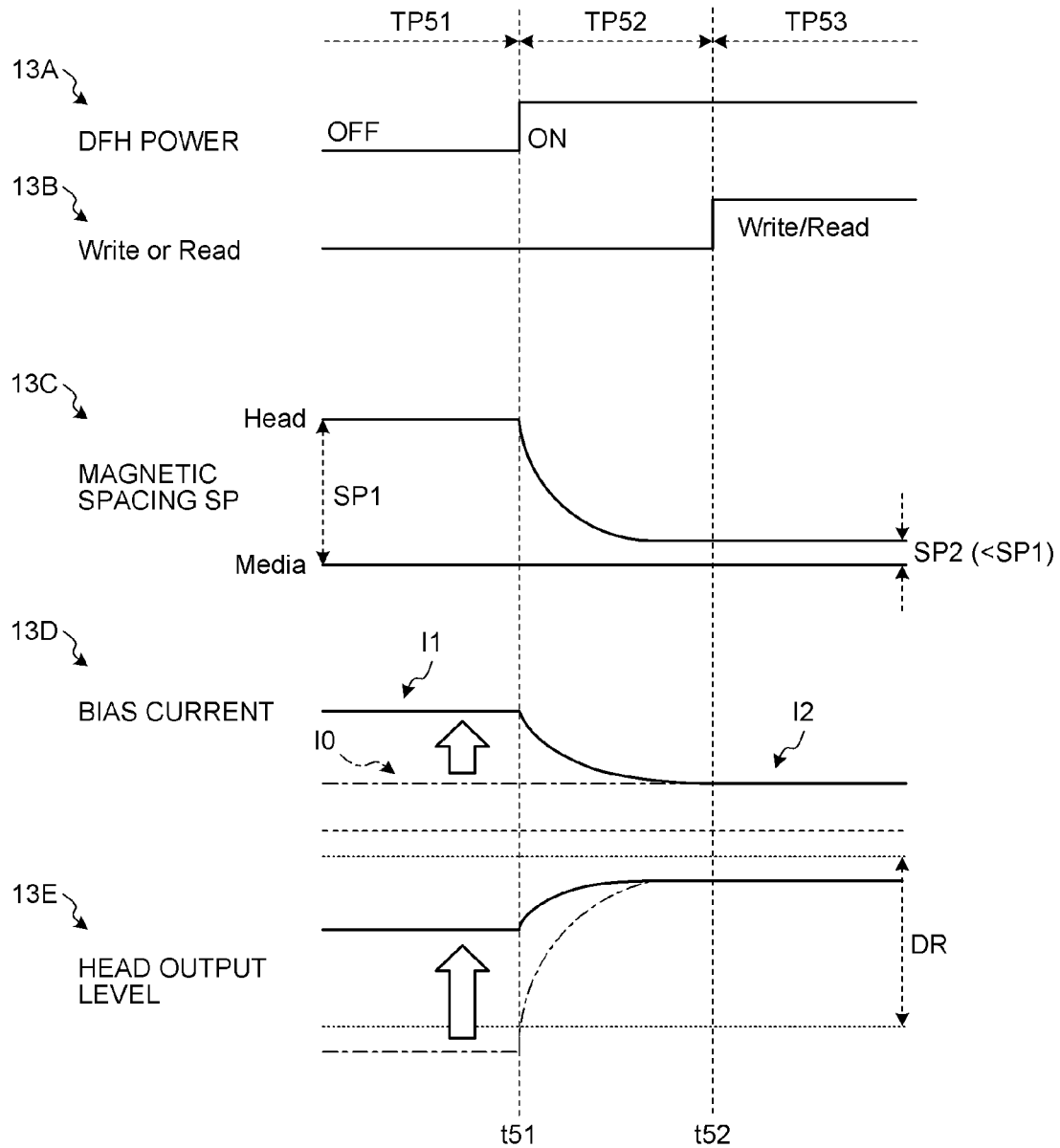


FIG. 14

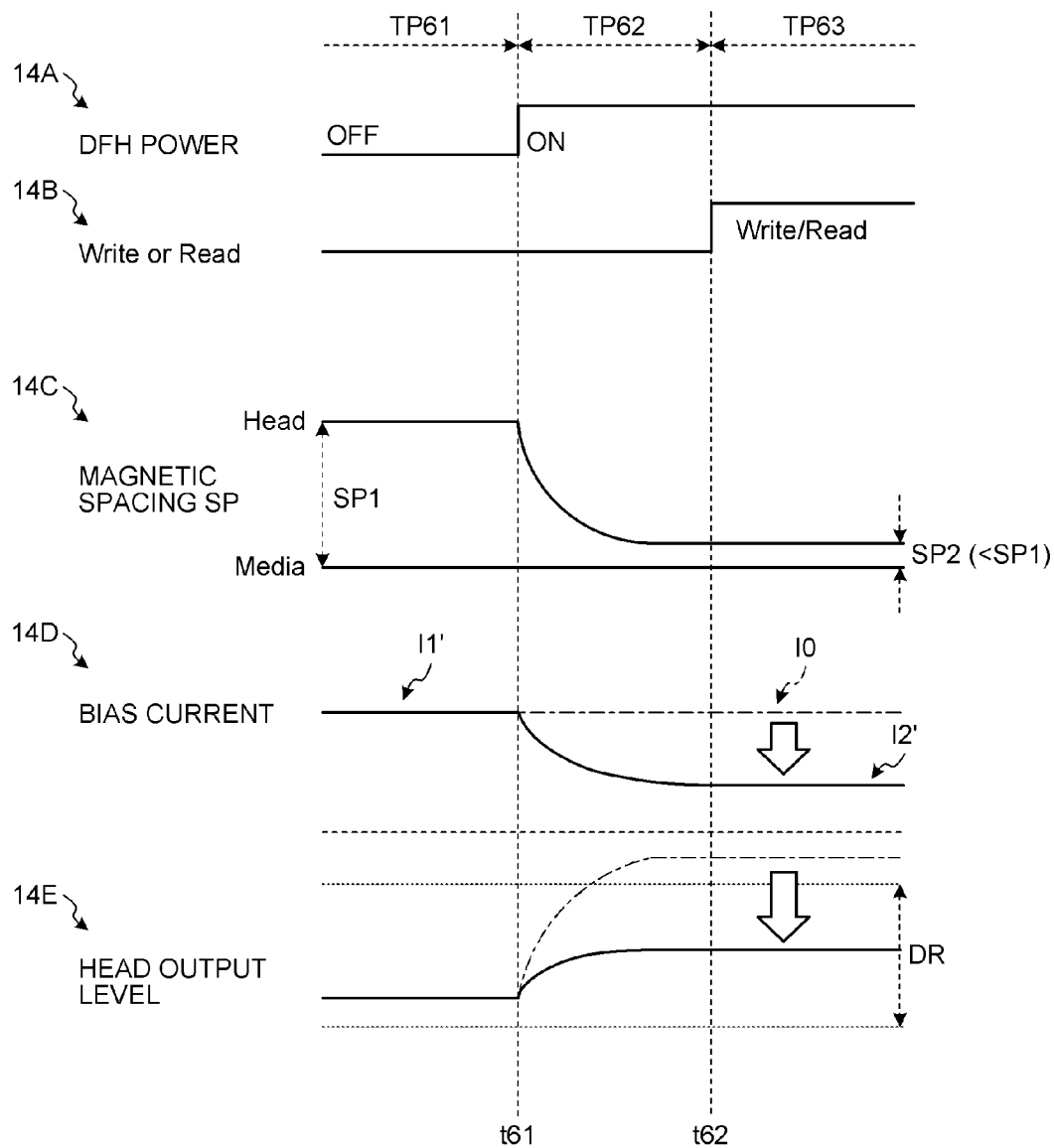
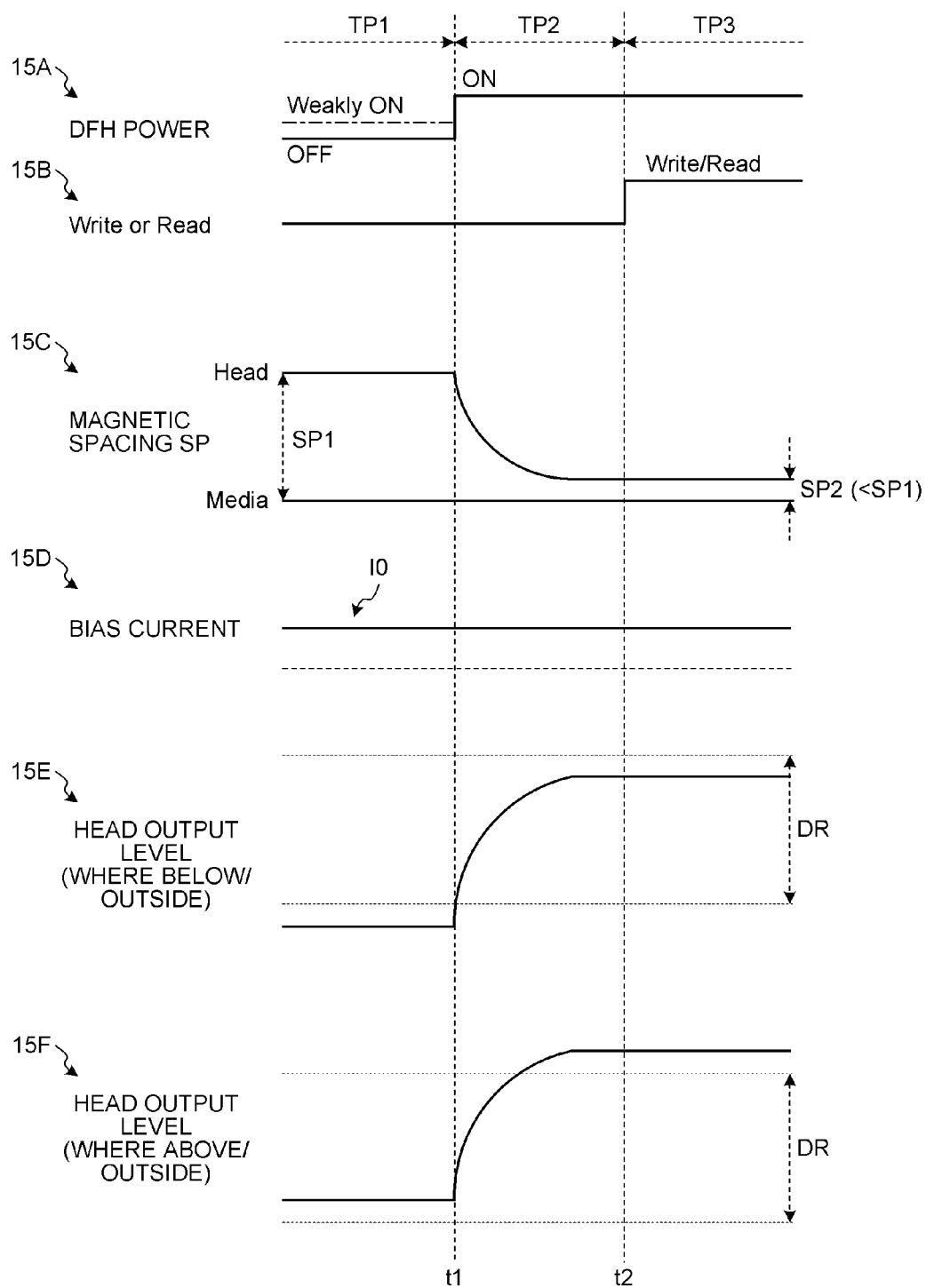


FIG. 15



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# MAGNETIC DISK DEVICE, HEAD AMPLIFIER, AND CONTROLLING METHOD OF MAGNETIC DISK DEVICE

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from Provisional Application No. 61/936,249, filed on Feb. 5, 2014; the entire contents of which are incorporated herein by reference.

## FIELD

Embodiments described herein relate generally to a magnetic disk device, head amplifier, and controlling method of the magnetic disk device.

## BACKGROUND

DFH (Dynamic Flying Height) control may be performed in magnetic disk devices. In the DFH control, by making current flow through a heater mounted on the magnetic head to make the magnetic head thermally expand, the magnetic spacing of the magnetic head from the magnetic disk is adjusted. At this time, it is desired to improve the error rate of information read out by the magnetic head.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram showing configuration of a magnetic disk device according to a first embodiment;

FIG. 2 is a diagram showing configuration of a magnetic head in the first embodiment;

FIG. 3 is a diagram showing configuration of the magnetic head in the first embodiment;

FIG. 4 is a diagram showing DFH (Dynamic Flying Height) control in the first embodiment;

FIG. 5 is a diagram showing control of bias current in the first embodiment;

FIG. 6 is a diagram showing control of bias current in the first embodiment;

FIG. 7 is a diagram showing configuration of a bias circuit in the first embodiment;

FIG. 8 is a diagram showing control of bias current in the first embodiment;

FIG. 9 is a diagram showing control where bias current is suddenly changed;

FIG. 10 is a diagram showing control of bias current in a modified example of the first embodiment;

FIG. 11 is a diagram showing configuration of a head amplifier in a second embodiment;

FIG. 12 is a diagram showing configuration of a bias circuit in the second embodiment;

FIG. 13 is a diagram showing control of bias current in the second embodiment;

FIG. 14 is a diagram showing control of bias current in the second embodiment; and

FIG. 15 is a diagram showing DFH control in basic form.

## DETAILED DESCRIPTION

In general, according to one embodiment, there is provided a magnetic disk device including a magnetic disk, a magnetic head, a heater, and a control unit. The magnetic head reads out information recorded on the magnetic disk. The heater is configured to adjust a magnetic spacing of the magnetic head

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from the magnetic disk. The control unit is configured to change a bias amount of the magnetic head according to setting of current flow through the heater.

Exemplary embodiments of a magnetic disk device will be explained below in detail with reference to the accompanying drawings. The present invention is not limited to the following embodiments.

## First Embodiment

The magnetic disk device according to the first embodiment will be described using FIG. 1. FIG. 1 is a diagram showing the configuration of the magnetic disk device 1.

The magnetic disk device 1 is, for example, a hard disk drive and functions as an external storage device for a host 40.

Specifically, the magnetic disk device 1 comprises a magnetic disk 11, a spindle motor 12, a magnetic head 22, an actuator arm 15, a voice coil motor (VCM) 16, a ramp 23, and a control unit 33. These constituents are placed within a housing (not shown).

The control unit 33 has a head amplifier 24 and a controller 32. The head amplifier 24 has a bias circuit 24a, a bias register 24b, and a power supply unit 24e. The controller 32 has a motor driver 21, a read write channel (RDC) 25, a hard disk controller (HDC) 31, a CPU 26, an SRAM 27, a flash ROM 28, and a buffer RAM 29.

The magnetic disk 11 is a disk-shaped recording medium on which to record a variety of information and is rotationally driven by a spindle motor 12. The magnetic disk 11 has multiple tracks in a concentric-circle shape with a point near the rotational center of the spindle motor 12 as their center. In each track, data areas DT and servo areas SV are alternately provided (see FIG. 8).

The actuator arm 15 is pivotally attached to a pivot 17. The magnetic head 22 is attached to one end of the actuator arm 15. The VCM 16 is connected to the other end of the actuator arm 15. The VCM 16 rotates the actuator arm 15 around the pivot 17 to position the magnetic head 22, in a lifted state, over an arbitrary radius location of the magnetic disk 11. At this time, the CPU 26 performs servo control (positioning control) to position the magnetic head 22 using a servo signal (servo information) read from the servo areas SV (see FIG. 8) by the magnetic head 22.

The motor driver 21, according to a command from the CPU 26, drives the spindle motor 12 to rotate the magnetic disk 11 at a predetermined rotational speed around the rotation axis. Further, the motor driver 21, according to a command from the CPU 26, drives the VCM 16 to move the magnetic head 22 at the end of the actuator arm 15 in a radius direction of the magnetic disk 11.

The magnetic head 22 writes data onto the magnetic disk 11 and reads information (data and servo information) recorded on the magnetic disk 11. The magnetic head 22 has, e.g., the configuration shown in FIGS. 2 and 3. FIG. 2 shows the configuration of the magnetic head 22 seen from the recording surface side of the magnetic disk 11, and FIG. 3 shows the configuration of the magnetic head 22 seen from the outer edge side of the magnetic disk 11.

The magnetic head 22 is configured to include a slider 205, a recording head 201, a reproducing head (MR head) 202, and a heater 204.

The recording head 201 writes data onto data areas of the magnetic disk 11 by the magnetic field generated from its magnetic poles. The reproducing head 202 reads change in the magnetic field on the magnetic disk 11 as data, thereby reading information (data and servo information) recorded on the magnetic disk 11. Note that when the rotation of the

magnetic disk **11** is stopped, and so on, the magnetic head **22** is evacuated onto the ramp **23** (see FIG. 1).

The heater **204** receives power supply from the power supply unit **24e** via the bias circuit **24a** to heat the slider **205** of the magnetic head **22**. By this heating, the slider **205** is deformed thermally, and thus the magnetic spacing SP of the magnetic head **22** from the magnetic disk **11** varies.

At read processing, the head amplifier **24** amplifies the signal (read signal) read by the reproducing head **202** from the magnetic disk **11** to output to the RDC **25**. At this time, the CPU **26** performs control for bias current to flow from the power supply unit **24e** via the bias circuit **24a** to the reproducing head **202**. The RDC **25** further amplifies the signal from the head amplifier **24**. The RDC **25** has an AGC circuit **25a** and performs AGC (Auto Gain Control) control using the AGC circuit **25a** to amplify the signal such that the signal level thereof becomes a predetermined target value.

At write processing, the head amplifier **24** amplifies a write signal supplied from the RDC **25** to output to the recording head **201**.

In the magnetic disk device **1**, at read processing and write processing, DFH (Dynamic Flying Height) control may be performed. In the DFH control, the CPU **26** performs control to supply power from the power supply unit **24e** via the bias circuit **24a** to the heater **204**. That is, the CPU **26** makes DFH power flow through the heater **204** mounted on the magnetic head **22** from the power supply unit **24e** via the bias circuit **24a** to make the magnetic head **22** thermally expand. By this means, the magnetic spacing SP of the magnetic head **22** from the magnetic disk **11** can be adjusted.

For example, the magnetic disk device **1** performs control as shown in FIG. 4. FIG. 4 is a schematic diagram for explaining the DFH control. In the magnetic head **22**, the heater **204** is mounted between the recording head **201** and the reproducing head **202**. The CPU **26** transmits a power supply command to the power supply unit **24e**, and the power supply unit **24e** having received this supplies power via the bias circuit **24a** to the heater **204** to heat the heater **204**. By this heating, as shown in 4A to 4B of FIG. 4, the slider **205** of the magnetic head **22** is thermally deformed, and thus the magnetic spacing SP of the recording head **201** and reproducing head **202** from the magnetic disk **11** can be changed from SP1 to SP2 (<SP1).

At write processing, as the magnetic spacing SP of the recording head **201** from the magnetic disk **11** is reduced, magnetic flux from the recording head **201** acts on the magnetic disk **11** more strongly, and hence the write characteristic can be improved, and thus the error rate of written data can be improved, and high surface density onto the magnetic disk **11** can be achieved.

At read processing, as the magnetic spacing SP of the reproducing head **202** from the magnetic disk **11** is reduced, magnetic force of the magnetic disk **11** acts on the reproducing head **202** more strongly, and hence the read characteristic can be improved, and thus the error rate of data and servo information at read processing can be improved, and high surface density onto the magnetic disk **11** can be achieved. The magnetic spacing SP controlled by the DFH control is sometimes called back off.

Consider the case where the bias current of the reproducing head **202** in the magnetic head **22** is kept at a constant value I0 all the time as shown in 15D of FIG. 15. FIG. 15 is a diagram showing the DFH control in the basic form.

When switching recording tracks, by making current flow through the VCM **16**, seek operation is performed by the actuator arm **15** having the magnetic head **22** mounted thereon. During the seek, the magnetic spacing SP of the

magnetic head **22** from the magnetic disk **11** may fluctuate because of wind disturbance due to a side wind that the actuator arm **15** receives or the like. During the seek, in order to avoid collision of the magnetic head **22** and the magnetic disk **11**, the DFH power flow through the heater **204** is turned off (the DFH control is OFF) as in time period TP1 shown in 15A of FIG. 15. Or, weaker DFH power than in a back-off state (time periods TP2, TP3) is made to flow through the heater **204** as indicated by the dot-dashed line in 15A of FIG. 15 (the DFH control is weakly ON).

That is, during the seek (time period TP1 preceding timing t1), the DFH power is smaller than when being on track, writing or reading (time period TP3 subsequent to timing t2) as shown in 15A of FIG. 15. Thus, the magnetic spacing SP1 in the seek (time period TP1) is larger than the magnetic spacing SP2 when writing/reading (time period TP3) (see 15C of FIG. 15). Hence, the output level of the reproducing head **202** in the seek (time period TP1) is smaller than the output level of the reproducing head **202** when writing/reading (time period TP3) (see 15E of FIG. 15).

That is, where the bias current of the reproducing head **202** is kept at the constant value I0 all the time, the output level of the reproducing head **202** in the seek (time period TP1) and the output level of the reproducing head **202** when writing/reading (time period TP3) may be greatly different.

The servo areas SV (see FIG. 8) are placed on the magnetic disk **11** at similar BPI (Bit Per Inch) for outer-side tracks and inner-side tracks. Thus, the output resolution of the reproducing head **202** is different between the outer-side tracks and inner-side tracks, and thus the output level of the reproducing head **202** may be different between the inner side and the outer side.

For the data areas DT (see FIG. 8) between the servo areas SV, there is usually used zone bit recording that partitions the magnetic disk **11** into a number of zones according to the radius location to change the transfer rate for each zone thereby making the BPI (Bit Per Inch) even across the surface substantially equal. Thus, the output resolution of the data area DT is not greatly different between the outer-side tracks and inner-side tracks. However, even in this case, the output level of the reproducing head **202** may vary depending on the characteristic of the magnetic head **22** (individual difference).

That is, in the situation where at read processing of data and servo information, the output level of the servo signal of the reproducing head **202** is likely to be greatly different according to ON/OFF of the DFH control, the error rates of the data signal and servo signal need to be kept lower than a required level. That is, in order that the HDC **31** performs error correction appropriately using the signals output from the RDC **25** to keep the error rates lower than the required level, the AGC control needs to be appropriately performed by the AGC circuit **25a** in the RDC **25** receiving the output of the reproducing head **202** of the magnetic head **22**. That is, the output level of the reproducing head **202** of the magnetic head **22** needs to be within the input dynamic range DR of the AGC circuit **25a**.

When the DFH control to make the magnetic spacing (back-off amount) SP smaller is performed to improve surface density, the output level of the reproducing head **202** may be greatly different between when the DFH control is OFF (time period TP1) and when the DFH control is ON (time period TP3). If the output level of the reproducing head **202** is greatly different between when the DFH control is OFF (time period TP1) and when ON (time period TP3), then the output level of the reproducing head **202** may deviate below from the input dynamic range DR of the AGC circuit **25a** when the DFH control is OFF (time period TP1) as shown in 15E of



FIG. 15. Hence, the AGC control is not appropriately performed by the AGC circuit 25a, and thus the error rate of the servo signal may deteriorate. Or, as shown in, e.g., 15F of FIG. 15, the output level of the reproducing head 202 may deviate above from the input dynamic range DR of the AGC circuit 25a when the DFH control is ON (time period TP3). Hence, the AGC control is not appropriately performed by the AGC circuit 25a, and thus the error rate of the data signal may deteriorate.

As such, when the output level of the reproducing head 202 deviates from the input dynamic range DR of the AGC circuit 25a, this increases the possibility that the AGC control is not appropriately performed by the AGC circuit 25a, and thus it can become difficult to improve the error rates of the data signal and servo signal, resulting in high possibility that improvement in surface density may be hampered.

Therefore, the present embodiment is aiming at making the output level of the reproducing head 202 be within the input dynamic range DR of the AGC circuit 25a by changing the bias current of the reproducing head 202 according to the ON/OFF setting of the DFH control.

Specifically, the control unit 33 changes the bias current of the magnetic head 22 following ON of the DFH control as shown in FIGS. 5 and 6. FIGS. 5 and 6 are diagrams showing the control of the bias current of the reproducing head 202.

The control unit 33, in response to the DFH power flow through the heater 204 being turned on, changes the bias current of the magnetic head 22 so that the output level of the magnetic head 22 comes within a predetermined range, that is, the input dynamic range DR of the AGC circuit 25a. The control unit 33, in response to the DFH power flow through the heater 204 being turned on, changes the bias current of the magnetic head 22 from a value I1 to a value I2. The value I1 is greater than the value I2. By changing the bias current of the magnetic head 22 (reproducing head 202) between when the DFH control is OFF and when the DFH control is ON, the difference in the output level of the magnetic head 22 can be made smaller. Also, the output level of the magnetic head 22 can be made to come within the input dynamic range of the AGC circuit 25a, thus achieving low back off.

For example, where it is understood from an experiment beforehand that if control of the basic form to keep the bias current constant all the time (see 15D of FIG. 15) is performed, the output level of the reproducing head 202 will deviate below from the input dynamic range DR of the AGC circuit 25a (see 15E of FIG. 15), the control unit 33 performs control of the bias current as shown in FIG. 5.

During time period TP11 preceding timing t11, the DFH power flow through the heater 204 is turned off by the control unit 33. In parallel with this, the controller 32 controls the bias current of the magnetic head 22 to be at the value I1. The value I1 is adjusted to be at a value greater than the value I2 (=I0) so that the output level of the magnetic head 22 (the reproducing head 202) is within the input dynamic range DR of the AGC circuit 25a (see 5D of FIG. 5).

At this time, since the DFH power flow through the heater 204 is off, the magnetic spacing SP of the magnetic head 22 from the magnetic disk 11 is at the large value SP1, but the bias current is controlled to be at the large value I1 corresponding to it. Thus, the output level of the magnetic head 22 (the reproducing head 202) can be within the input dynamic range DR of the AGC circuit 25a as shown in 5E of FIG. 5.

When at timing t11 the control unit 33 turns on the DFH power flow through the heater 204, the magnetic spacing SP of the magnetic head 22 from the magnetic disk 11 starts

decreasing from the value SP1. The control unit 33 starts accordingly decreasing the bias current of the magnetic head 22.

That is, during time period TP12 from timing t11 to timing t12, the magnetic spacing SP of the magnetic head 22 from the magnetic disk 11 gradually decreases from the value SP1 to the value SP2. The control unit 33 accordingly changes the bias current of the magnetic head 22 from the value I1 to the value I2 in a stepwise manner. The value I2 may be substantially equal to the value I0 in the basic form (see 15D of FIG. 15).

At timing t12, the magnetic spacing SP is at the value SP2 while the control unit 33 is controlling the bias current of the magnetic head 22 to be at the value I2. Accordingly, the control unit 33 starts write processing of data or read processing of information (data, servo).

During time period TP13 subsequent to timing t12, the control unit 33 keeps the bias current of the magnetic head 22 to be at the value I2. In this state, the control unit 33 performs write processing of data or read processing of information (data, servo).

Or, for example, where it is understood from an experiment beforehand that if control of the basic form to keep the bias current constant all the time (see 15D of FIG. 15) is performed, the output level of the reproducing head 202 will deviate above from the input dynamic range DR of the AGC circuit 25a (see 15F of FIG. 15), the control unit 33 performs control of the bias current as shown in FIG. 6. The control of the bias current as shown in FIG. 6 is basically similar to control of the bias current as shown in FIG. 5, but differs in the following points.

During time period TP21 preceding timing t21, the control unit 33 controls the bias current of the magnetic head 22 to be at the value I1'. The value I1' may be substantially equal to the value I0 in the basic form (see 15D of FIG. 15).

During time period TP22 from timing t21 to timing t22, the control unit 33 changes the bias current of the magnetic head 22 from the value I1' to the value I2' in a stepwise manner. During time period TP23 subsequent to timing t22, the controller 32 keeps the bias current of the magnetic head 22 to be at the value I2'. The value I2' is adjusted to be at a value smaller than the value I1' (=I0) so that the output level of the magnetic head 22 (the reproducing head 202) is within the input dynamic range DR of the AGC circuit 25a (see 6D of FIG. 6).

At this time, since the DFH power flow through the heater 204 is on, the magnetic spacing SP of the magnetic head 22 from the magnetic disk 11 is at the small value SP2, but the bias current is controlled to be at the small value I2' corresponding to it. Thus, the output level of the magnetic head 22 (the reproducing head 202) can be within the input dynamic range DR of the AGC circuit 25a as shown in 6E of FIG. 6.

Next, the configuration and operation of the head amplifier 24 will be described using FIGS. 1 and 7. FIG. 7 is a diagram showing the configuration of the head amplifier 24.

The head amplifier 24 has the bias circuit 24a, the bias register 24b, and the power supply unit 24e as shown in FIG. 1. The bias register 24b holds a control value for the bias current. The bias circuit 24a generates the bias current using electric power from the power supply unit 24e according to the control value held in the bias register 24b. The control value held in the bias register 24b is a digital value having multiple bits b1 to b4.

For example, the bias circuit 24a has multiple switches SW1 to SW4 and multiple resistors R1 to R4 as shown in FIG. 7. In the bias circuit 24a, multiple sets of switch SW1 to SW4 and resistor R1 to R4 respectively connected serially are

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connected in parallel between an input terminal **24a1** and an output terminal **24a2**. The multiple switches **SW1** to **SW4** correspond to the multiple resistors **R1** to **R4** and correspond to the multiple bits **b1** to **b4** of the control value of the bias register **24b**.

Each switch **SW1** to **SW4** can switch between the corresponding resistor **R1** to **R4** being connected between the input terminal **24a1** and the output terminal **24a2** and the corresponding resistor **R1** to **R4** not being connected according to the corresponding bit **b1** to **b4**. When the corresponding bit **b1** to **b4** is active (e.g., 1), each switch **SW1** to **SW4** is turned on, so that the corresponding resistor **R1** to **R4** is electrically inserted between the input terminal **24a1** and the output terminal **24a2**. When the corresponding bit **b1** to **b4** is non-active (e.g., 0), each switch **SW1** to **SW4** is turned off, so that the corresponding resistor **R1** to **R4** is electrically separated from between the input terminal **24a1** and the output terminal **24a2**.

The resistors **R1** to **R4** can be configured to have different resistances respectively. The conductance values (reciprocals of the resistances) of the resistors **R1** to **R4** can be set to satisfy the following expression 1.

$$1/(R1):1/(R2):1/(R3):1/(R4)=\sigma:2\sigma:4\sigma:8\sigma \quad \text{Expression 1}$$

By setting them to satisfy the expression 1, the combined conductance value of the bias circuit **24a** can be varied by units of conductance value  $\sigma$  according to the bits **b1** to **b4**, so that the bias current can be varied by units corresponding to the conductance value  $\sigma$ . For example, during time period **TP12** shown in FIG. 5 and time period **TP22** shown in FIG. 6, the controller **32** (CPU **26**) can access the bias register **24b** to rewrite the control value therein, thereby changing the bias current of the magnetic head **22** from the value **I1** (**I1'**) to the value **I2** (**I2'**) in a stepwise manner by units corresponding to the conductance value  $\sigma$ .

Here, consider the case where the controller **32** changes the bias current of the magnetic head **22** sharply in binary in response to the current flow through the heater **204** being turned on as shown in **9A** of FIG. 9. FIG. 9 is a diagram showing control where the bias current is sharply changed. In this case, the output level of the magnetic head **22** (the reproducing head **202**) changes sharply in binary as shown in **9D** of FIG. 9. Hence, the signal after AGC by the AGC circuit **25a** changes as shown in **9E** of FIG. 9, and thus the AGC control may become unstable. The amplitude of the signal after AGC may increase from amplitude **AM1** to amplitude **AM2** and then decrease to amplitude **AM3**. Or, as shown in **9F** of FIG. 9, the AGC control does not follow immediately, but tries to catch up, and may become unstable. The amplitude of the signal after AGC may increase from amplitude **AM1** to amplitude **AM4** and then decrease to amplitude **AM5**. If the AGC control becomes unstable, seek control may also be affected.

In contrast, in the present embodiment, the controller **32** (CPU **26**) can access the bias register **24b** to rewrite the control value therein as shown in FIG. 8, thereby changing the bias current of the magnetic head **22** from the value **I1** to the value **I2** in a stepwise manner by units corresponding to the conductance value  $\sigma$ .

For example, during the time period preceding timing **t31** between servo timing **svt1** and servo timing **svt2** shown in FIG. 8, the control value of the bias register **24b** is set at **0Ah**. At this time, when (**b1**, **b2**, **b3**, **b4**), shown in FIG. 7, = (0, 1, 0, 1), the resistors **R2**, **R4** are selectively inserted between the input terminal **24a1** and the output terminal **24a2** in the bias circuit **24a**, so that the combined conductance becomes  $10\sigma$ . Accordingly the bias circuit **24a** supplies the bias current of the value **I1** to the magnetic head **22**.

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At timing **t31** shown in FIG. 8, the controller **32** rewrites the control value of the bias register **24b** to be at **09h**. At this time, when (**b1**, **b2**, **b3**, **b4**), shown in FIG. 7, = (1, 0, 0, 1), the resistors **R1**, **R4** are selectively inserted between the input terminal **24a1** and the output terminal **24a2** in the bias circuit **24a**, so that the combined conductance becomes  $9\sigma$ . Accordingly the bias circuit **24a** supplies the bias current of a value **I3** ( $<I1$ ) to the magnetic head **22**.

At timing **t32** between servo timing **svt2** and servo timing **svt3** shown in FIG. 8, the controller **32** rewrites the control value of the bias register **24b** to be at **08h**. At this time, when (**b1**, **b2**, **b3**, **b4**), shown in FIG. 7, = (0, 0, 0, 1), the resistor **R4** is selectively inserted between the input terminal **24a1** and the output terminal **24a2** in the bias circuit **24a**, so that the combined conductance becomes  $8\sigma$ . Accordingly the bias circuit **24a** supplies the bias current of a value **I4** ( $<I3$ ) to the magnetic head **22**.

At timing **t33** between servo timing **svt3** and servo timing **svt4** shown in FIG. 8, the controller **32** rewrites the control value of the bias register **24b** to be at **07h**. At this time, when (**b1**, **b2**, **b3**, **b4**), shown in FIG. 7, = (1, 1, 1, 0), the resistors **R1**, **R2**, **R3** are selectively inserted between the input terminal **24a1** and the output terminal **24a2** in the bias circuit **24a**, so that the combined conductance becomes  $7\sigma$ . Accordingly the bias circuit **24a** supplies the bias current of the value **I2** ( $<I4$ ) to the magnetic head **22**.

As such, bias setting is performed between servo areas **SV** during the seek, thereby changing the bias current in a stepwise manner, and hence the output (servo output) of the magnetic head **22** can be changed in a stepwise manner. By this means, the bias current can be approximately linearly changed from the value **I1** to the value **I2** as indicated by the dot-dashed line in **8A** of FIG. 8. As a result, the AGC control by the AGC circuit **25a** can be caused to easily follow the output of the magnetic head **22** as shown in **8D** of FIG. 8, and thus the amplitude of the signal after AGC can be stably kept at amplitude **AM1**, resulting in the AGC control being stabilized and the seek control being stabilized.

It should be noted that, although FIG. 8 illustratively shows the case where the bias current is changed in four steps (taking on four values), the number of steps in which the bias current is changed may be increased. By increasing the number of steps in which the bias current is changed, change in the bias current can be made further close to linear change.

As described above, in the first embodiment, in the magnetic disk device **1**, the control unit **33** changes the bias current of the magnetic head **22** according to the setting for the current flow through the heater **204**. Specifically, the control unit **33**, in response to the current flow through the heater **204** being turned on, changes the bias current of the magnetic head **22** from the value **I1** to the value **I2** ( $<I1$ ). Thus, the output level of the magnetic head **22** (the reproducing head **202**) can be within the input dynamic range **DR** of the AGC circuit **25a**, and hence the AGC control can be easily performed by the AGC circuit **25a**. As a result, the error rates of the data signal and servo signal can be improved, and hence the surface density of recording onto the magnetic disk **11** can be improved.

Further, in the first embodiment, in the magnetic disk device **1**, the control unit **33**, in response to the current flow through the heater **204** being turned on, changes the bias current of the magnetic head **22** in a stepwise manner from the value **I1** to the value **I2** ( $<I1$ ). Thus, the bias current can be approximately linearly changed from the value **I1** to the value **I2**, and hence the AGC control by the AGC circuit **25a** can be caused to easily follow the output of the magnetic head **22**, and thus the amplitude of the signal after AGC can be stably

kept at amplitude AM1. As a result, the AGC control by the AGC circuit 25a can be stabilized, and the seek control by the CPU 26 can be stabilized.

Yet further, in the first embodiment, in the control unit 33 of the magnetic disk device 1, the controller 32, correspondingly to the current flow through the heater 204 being off, sets the control value of the bias register 24b at a first control value (control value 0Ah). The control unit 33, correspondingly to the current flow through the heater 204 being on, sets the control value in the bias register 24b at a second control value (control value 07h) corresponding to a smaller bias current value than the first control value. Thus, the bias current of the magnetic head 22 can be changed from the value I1 to the value I2 (<I1).

Still further, in the first embodiment, in the control unit 33 of the magnetic disk device 1, the controller 32, in response to the current flow through the heater 204 being turned on, sets the control value of the bias register 24b to change in a stepwise manner from the first control value to the second control value. For example, the controller 32, at timings between servo timings svt1 to svt4, which pass during the time from when the current flow through the heater 204 is turned on until the magnetic spacing SP of the magnetic head 22 becomes stable, sets the control value of the bias register 24b to change in a stepwise manner from the first control value to the second control value. Thus, the bias current of the magnetic head 22 can be changed in a stepwise manner from the value I1 to the value I2 (<I1).

It should be noted that, although FIGS. 2 to 4 illustratively show the case where the heater 204 is provided in the slider 205 of the magnetic head 22, the heater 204 may be provided outside the slider 205 as long as the configuration is made such that the slider 205 can be thermally deformed so that the magnetic spacing SP of the recording head 201 from the magnetic disk 11 becomes smaller.

Alternatively, although FIG. 8 illustratively shows the case where the bias current of the magnetic head 22 is changed by substantially the same variation amount when being changed in a stepwise manner from the value I1 to the value I2 (<I1), the bias current may be changed by a gradually decreasing variation amount in a stepwise manner from the value I1 to the value I2 (<I1). This will be explained using FIG. 10.

For example, during the time period preceding timing t41 between servo timing svt11 and servo timing svt12 shown in FIG. 10, the control value of the bias register 24b is set at 15h. At this time, when (b1, b2, b3, b4), shown in FIG. 7, =(1, 1, 1, 1), the resistors R1, R2, R3, R4 are inserted between the input terminal 24a1 and the output terminal 24a2 in the bias circuit 24a, so that the combined conductance becomes 15σ. Accordingly the bias circuit 24a supplies the bias current of the value I1 to the magnetic head 22.

At timing t41 shown in FIG. 10, the controller 32 rewrites the control value of the bias register 24b to be at 10h. At this time, when (b1, b2, b3, b4), shown in FIG. 7, =(0, 1, 0, 1), the resistors R2, R4 are selectively inserted between the input terminal 24a1 and the output terminal 24a2 in the bias circuit 24a, so that the combined conductance becomes 10σ. Accordingly the bias circuit 24a supplies the bias current of a value I5 (<I1) to the magnetic head 22.

At timing t42 between servo timing svt12 and servo timing svt13 shown in FIG. 10, the controller 32 rewrites the control value of the bias register 24b to be at 08h. At this time, when (b1, b2, b3, b4), shown in FIG. 7, =(0, 0, 0, 1), the resistor R4 is selectively inserted between the input terminal 24a1 and the output terminal 24a2 in the bias circuit 24a, so that the combined conductance becomes 8σ. Accordingly the bias

circuit 24a supplies the bias current of a value I6 (<I5) to the magnetic head 22. At this time, the following expression 2 holds.

$$|I6-I5| < |I5-I1|$$

Expression 2

At timing t43 between servo timing svt13 and servo timing svt14 shown in FIG. 10, the controller 32 rewrites the control value of the bias register 24b to be at 07h. At this time, when (b1, b2, b3, b4), shown in FIG. 7, =(1, 1, 1, 0), the resistors R1, R2, R3 are selectively inserted between the input terminal 24a1 and the output terminal 24a2 in the bias circuit 24a, so that the combined conductance becomes 7σ. Accordingly the bias circuit 24a supplies the bias current of the value I2 (<I6) to the magnetic head 22. At this time, the following expression 3 holds.

$$|I2-I6| < |I6-I5|$$

Expression 3

As such, bias setting is performed between servo areas SV during the seek, thereby changing the bias current in a stepwise manner by a gradually decreasing variation amount, and hence the output (servo output) of the magnetic head 22 can be changed in a stepwise manner by a gradually decreasing variation amount. By this means, the bias current can be changed from the value I1 to the value I2 approximately along with a characteristic corresponding to the change characteristic of the magnetic spacing SP as indicated by the dot-dashed line in 10A of FIG. 10. As a result, the AGC control by the AGC circuit 25a can be caused to further easily follow the output of the magnetic head 22, and thus the amplitude of the signal after AGC can be stably kept at amplitude AM1, resulting in the AGC control being further stabilized.

Alternatively, although the first embodiment illustratively describes the case where the bias current of the magnetic head 22 is controlled for the bias of the magnetic head 22, the bias voltage of the magnetic head 22 may be controlled instead of the bias current of the magnetic head 22.

## Second Embodiment

Next, the magnetic disk device according to the second embodiment will be described. Description will be made below focusing on the differences from the first embodiment.

Although in the first embodiment the bias current of the magnetic head 22 is changed in a stepwise manner from the value I1 to the value I2 (<I1), in the second embodiment, the bias current of the magnetic head 22 is changed autonomously from the value I1 to the value I2 (<I1).

Specifically, the control unit 133 of the magnetic disk device 100 has a head amplifier 124 as shown in FIG. 11 instead of the head amplifier 24 (see FIG. 1). FIG. 11 is a diagram showing the configuration of the head amplifier 124. The head amplifier 124 comprises a circuit having a time constant and in response to the current flow through the heater 204 being turned on, changes the bias current to be generated from the value I1 to the value I2 (<I1) according to the time constant thereof.

That is, the head amplifier 124 has a bias circuit 124a, an off bias register (first register) 124b, an on bias register (second register) 124c, a time constant register (third register) 124d, and a power supply unit 24e. The off bias register 124b holds a control value for the bias current corresponding to the current flow through the heater 204 being off. The on bias register 124c holds a control value for the bias current corresponding to the current flow through the heater 204 being on. The time constant register 124d holds a control value for the time constant.

The bias circuit 124a has the time constant. The bias circuit 124a, in response to the current flow through the heater 204

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being turned on, generates the bias current while changing the value of the bias current from the control value held in the on bias register **124c** to the control value held in the off bias register **124b** at the time constant corresponding to the control value held in the time constant register **124d**. The bias circuit **124a** supplies the generated bias current to the magnetic head **22** (the reproducing head **202**).

Specifically, the bias circuit **124a** has the configuration as shown in FIG. **12**. FIG. **12** is a diagram showing the configuration of the bias circuit **124a**. In the bias circuit **124a**, an on bias setting block **B1**, an off bias setting block **B2**, and a time constant setting block **B3** are connected serially between an input terminal **124a1** and an output terminal **124a2**.

The on bias setting block **B1** has multiple switches **SW11** to **SW14** and multiple resistors **R11** to **R14**. In the on bias setting block **B1**, some of the resistors **R11** to **R14** can be connected between an input node **B11** and an output node **B12** according to the on/off of the switches **SW11** to **SW14**. The multiple switches **SW11** to **SW14** correspond to the multiple resistors **R11** to **R14** and correspond to the multiple bits **b11** to **b14** of the control value of the on bias register **124c**.

Each switch **SW11** to **SW14** can connect the corresponding resistor **R11** to **R14** between the input node **B11** and the output node **B12** according to the corresponding bit **b11** to **b14**. The conductance values (reciprocals of the resistances) of the resistors **R11** to **R14** can be set to satisfy the following expression 4.

$$1/(R11):1/(R12):1/(R13):1/(R14)=\sigma':2a':4a':8a' \quad \text{Expression 4}$$

By setting them to satisfy the expression 4, the combined conductance value of the on bias setting block **B1** can be varied by units of conductance value  $\sigma'$  according to the bits **b11** to **b14**, so that on-bias current can be set to vary by units corresponding to the conductance value  $\sigma'$ .

The off bias setting block **B2** has a variable gain amplifier AMP. The variable gain amplifier AMP is connected on its input side to an input node **B21** and on its output side to an output node **B22**. The gain of the variable gain amplifier AMP corresponds to the multiple bits **b21** to **b22** of the control value of the off bias register **124b**. By changing the gain of the variable gain amplifier AMP, off-bias current can be set to vary.

The time constant setting block **B3** has multiple switches **SW31** to **SW34** and multiple capacitors **C31** to **C34**. In the time constant setting block **B3**, some of the capacitors **C31** to **C34** can be connected between an input node **B31** and an output node **B32** according to the on/off of the switches **SW31** to **SW34**. The multiple switches **SW31** to **SW34** correspond to the multiple capacitors **C31** to **C34** and correspond to the multiple bits **b31** to **b34** of the control value of the time constant register **124d**.

Each switch **SW31** to **SW34** can connect the corresponding capacitor **C31** to **C34** between the input node **B31** and the output node **B32** according to the corresponding bit **b31** to **b34**. When the corresponding bit **b31** to **b34** is active (e.g., 1), each switch **SW31** to **SW34** makes the corresponding capacitor **C31** to **C34** electrically inserted between the input node **B31** and the output node **B32**. When the corresponding bit **b31** to **b34** is non-active (e.g., 0), each switch **SW31** to **SW34** makes the corresponding capacitor **C31** to **C34** electrically separated from between the input node **B31** and the output node **B32**.

The capacitors **C31** to **C34** can be configured to have different capacitance values respectively. The capacitance values of the capacitors **C31** to **C34** can be set to satisfy the following expression 5.

$$C31:C32:C33:C34=c:2c:4c:8c \quad \text{Expression 5}$$

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By setting them to satisfy the expression 5, the combined capacitance value of the time constant setting block **B3** can be varied by units of capacitance value  $c$  according to the bits **b31** to **b34**, so that the time constant of the bias circuit **124a** can be varied by units corresponding to the capacitance value  $c$ .

With this configuration, the head amplifier **124** autonomously changes the bias current of the magnetic head **22** following ON of the DFH control as shown in FIGS. **13** and **14**. FIGS. **13** and **14** are diagrams showing the control of the bias current.

For example, where it is understood from an experiment beforehand that if control of the basic form to keep the bias current constant all the time (see **15D** of FIG. **15**) is performed, the output level of the reproducing head **202** will deviate below from the input dynamic range DR of the AGC circuit **25a** (see **15E** of FIG. **15**), the control unit **133** performs control of the bias current as shown in FIG. **13**.

During time period TP51 preceding timing t51, the controller **32** accesses the off bias register **124b** beforehand to set the control value corresponding to the value **I1** of the bias current in the off bias register **124b**. The bias circuit **124a** keeps the bias current of the magnetic head **22** at the value **I1** according to the control value of the off bias register **124b**. The value **I1** is adjusted to be at a value greater than the value **I2** ( $\approx I0$ ) so that the output level of the magnetic head **22** (the reproducing head **202**) is within the input dynamic range DR of the AGC circuit **25a** (see **13D** of FIG. **13**).

At timing t51, the controller **32** accesses the on bias register **124c** to set the control value corresponding to the value **I2** of the bias current in the on bias register **124c**. The controller **32** selects a time constant corresponding to a characteristic close to the change characteristic (see **13C** of FIG. **13**) of the magnetic spacing SP from among multiple time constants that are candidates to be set. The controller **32** accesses the time constant register **124d** to set the control value corresponding to the selected time constant in the time constant register **124d**.

Thus, during time period TP52 from timing t51 to timing t52, the head amplifier **124** autonomously changes the bias current of the magnetic head **22** from the value **I1** to the value **I2** at the time constant set in the time constant register **124d**. The value **I2** may be substantially equal to the value **I0** in the basic form (see **15D** of FIG. **15**).

During time period TP53 subsequent to timing t52, the head amplifier **124** keeps the bias current of the magnetic head **22** at the value **I2**.

Or, for example, where it is understood from an experiment beforehand that if control of the basic form to keep the bias current constant all the time (see **15D** of FIG. **15**) is performed, the output level of the reproducing head **202** will deviate above from the input dynamic range DR of the AGC circuit **25a** (see **15F** of FIG. **15**), the control unit **133** performs control of the bias current as shown in FIG. **14**.

During time period TP61 preceding timing t61, the bias circuit **124a** keeps the bias current of the magnetic head **22** at the value **I1'** according to the control value of the off bias register **124b**. The value **I1'** may be substantially equal to the value **I0** in the basic form (see **15D** of FIG. **15**).

At timing t61, the controller **32** accesses the on bias register **124c** to set the control value corresponding to the value **I2'** of the bias current in the on bias register **124c**. The controller **32** selects a time constant corresponding to a characteristic close to the change characteristic (see **14C** of FIG. **14**) of the magnetic spacing SP from among multiple time constants that are candidates to be set. The controller **32** accesses the

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time constant register **124d** to set the control value corresponding to the selected time constant in the time constant register **124d**.

Thus, during time period TP62 from timing t61 to timing t62, the head amplifier **124** autonomously changes the bias current of the magnetic head **22** from the value I1' to the value I2' at the time constant set in the time constant register **124d**. During time period TP63 subsequent to timing t62, the control unit **33** keeps the bias current of the magnetic head **22** at the value I2'. The value I2' is adjusted to be at a value smaller than the value I1' so that the output level of the magnetic head **22** (the reproducing head **202**) is within the input dynamic range DR of the AGC circuit **25a** (see **14D** of FIG. **14**).

As described above, in the second embodiment, the head amplifier **124** in the control unit **133** of the magnetic disk device **100** generates the bias current to supply to the magnetic head **22** while autonomously changing the value of the bias current according to the setting of current flow through the heater **204**. Specifically, the head amplifier **124** comprises a circuit having a time constant and, in response to the current flow through the heater **204** being turned on, changes the bias current to be generated from the value I1 to the value I2 according to the time constant thereof. By this means, the change characteristic of the bias current can be made further close to the change characteristic of the magnetic spacing SP, and thus the output level of the magnetic head **22** (the reproducing head **202**) can be changed smoothly as shown in **13E** of FIGS. **13** and **14E** of FIG. **14**. As a result, the AGC control by the AGC circuit **25a** can be caused to further easily follow the output of the magnetic head **22**, and thus the amplitude of the signal after AGC can be stably kept at amplitude AM1, resulting in the AGC control by the AGC circuit **25a** being further stabilized.

Further, in the second embodiment, the bias circuit **124a** in the head amplifier **124**, in response to the current flow through the heater **204** being turned on, generates the bias current while changing the value of the bias current from the value corresponding to the control value held in the on bias register **124c** to the value corresponding to the control value held in the off bias register **124b** at the time constant corresponding to the control value held in the time constant register **124d**. By this means, the bias circuit **124a** can autonomously change the bias current without the need for the controller **32** (CPU **26**) to rewrite the control values of the registers sequentially, and thus the control contents of the controller **32** can be simplified.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A magnetic disk device comprising:

- a magnetic disk;
- a magnetic head that reads out information recorded on the magnetic disk;
- a heater configured to adjust a magnetic spacing of the magnetic head from the magnetic disk; and
- a control unit configured to change a bias amount of the magnetic head according to setting of current flow through the heater, wherein the control unit comprises:

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a head amplifier comprising a register configured to hold a control value for the bias amount and a bias circuit configured to generate a bias according to the control value held in the register and to supply generated bias to the magnetic head; and

a controller configured to set the control value of the register to a first control value correspondingly to off state of the current flow through the heater and to set the control value of the register to a second control value correspondingly to a smaller bias value than a bias value corresponding to the first control value correspondingly to on state of the current flow through the heater.

2. The magnetic disk device according to claim 1, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head so that output level of the magnetic head is within a particular range.
3. The magnetic disk device according to claim 1, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head from a first value to a second value smaller than the first value.
4. The magnetic disk device according to claim 3, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head in a stepwise manner from the first value to the second value.
5. The magnetic disk device according to claim 3, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head in a stepwise manner by a gradually decreasing variation amount from the first value to the second value.
6. The magnetic disk device according to claim 1, wherein the controller, in response to the current flow through the heater being turned on, sets the control value of the register so as to change in a stepwise manner from the first control value to the second control value.
7. The magnetic disk device according to claim 1, wherein the controller sets the control value of the register so as to change in a stepwise manner from the first control value to the second control value at timings between multiple servo timings which pass during time from when the current flow through the heater is turned on until the magnetic spacing of the magnetic head becomes stable.
8. A magnetic disk device comprising:
  - a magnetic disk;
  - a magnetic head that reads out information recorded on the magnetic disk;
  - a heater configured to adjust a magnetic spacing of the magnetic head from the magnetic disk; and
  - a control unit including a head amplifier configured to generate a bias to supply to the magnetic head while autonomously changing the value of the bias amount according to the setting of the current flow through the heater,

the head amplifier comprising:

- a first register configured to hold a control value for the bias amount corresponding to off state of the current flow through the heater;
- a second register configured to hold a control value for the bias amount corresponding to on state of the current flow through the heater;
- a third register configured to hold a control value for the time constant; and

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a bias circuit configured to generate a bias, in response to the current flow through the heater being turned on, while changing the bias amount from a value corresponding to the control value held in the first register to a value corresponding to the control value held in the second register with a time constant corresponding to the control value held in the third register.

9. A head amplifier for a magnetic disk device that comprises a heater configured to adjust a magnetic spacing of a magnetic head configured to read out information recorded on the magnetic disk from a magnetic disk,

the head amplifier generating a bias to supply to the magnetic head while autonomously changing value of a bias amount according to setting of current flow through the heater,

the head amplifier comprising:

a first register configured to hold a control value for the bias amount corresponding to off state of the current flow through the heater;

a second register configured to hold a control value for the bias amount corresponding to on state of the current flow through the heater;

a third register configured to hold a control value for the time constant; and

a bias circuit configured to generate a bias, in response to the current flow through the heater being turned on, while changing the bias amount from the first value

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corresponding to the control value held in the first register to the second value corresponding to the control value held in the second register with a time constant corresponding to the control value held in the third register.

10. The magnetic disk device according to claim 8, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head so that output level of the magnetic head is within a particular range.

11. The magnetic disk device according to claim 8, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head from a first value to a second value smaller than the first value.

12. The magnetic disk device according to claim 11, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head in a stepwise manner from the first value to the second value.

13. The magnetic disk device according to claim 11, wherein the control unit, in response to the current flow through the heater being turned on, changes the bias amount of the magnetic head in a stepwise manner by a gradually decreasing variation amount from the first value to the second value.

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